TR-955

A METHOD OF ANALYZING UNKNOWN SIGNAL PARAMETERS

Frank Vrataric

258 200

30 June 1961

DIAMOND ORDNANCE FUZE LABORATORIES
ORDNANCE CORPS ● DEPARTMENT OF THE ARMY
WASHINGTON 25, D. C.

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DA 5N06-01-001
DA 5N16-01-004

OMS 5210.11.11100
OMS 5210.11.14600.01
OMS 2860.50.00000

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CONTENTS

ABSTRACT

A simple inexpensive method of analyzing and/or determining signal parameters of unknown purpose or origin, including signals in the presence of noise, is described. The method is an adaption of intensity modulation techniques used in radar systems and employs readily available laboratory equipment. It also employs a moving film camera but techniques for obtaining quasi-instantaneous outputs are described. Other possible uses, such as phase detection, frequency comparison and telemetry evaluation are also described.

1. INTRODUCTION

The detection, demodulation and analysis of unknown signal parameters are usually expensive and laborious tasks. This is especially true of weak signals in the presence of noise.

This report describes a method of correlating these types of signals as a function of time. The method utilizes intensity modulation techniques and readily available laboratory equipment. It provides the user with a valuable analytical tool in evaluating signal parameters as well as design parameters for the more elaborate systems.

The feasibility of this technique has been demonstrated in the laboratory. Its use has effected a substantial saving of time and funds in evaluating telemetry signals. It has also been used, with considerable success, in analyzing other types of signals. The techniques of the system will suggest its use in many other applications where a time measurement is involved. Some of these applications are described.

It is recognized that intensity modulation techniques are being used in radar systems and perhaps in other specialized cases. However, a search of the literature and discussions with personnel from DOFL and other Department of Defense agencies (ref 1) failed to yield evidence of this technique being used in the manner described in this report.

The idea, for this technique, evolved while investigating ionospheric disturbances, utilizing back-scatter radar techniques, in a project sponsored by ARGMA (OAMC). The work covering this report was funded by DOFL, ARGMA and OTIA.

2. INTENSITY MODULATION

Intensity modulation, as described in this report, is the modulation of intensity of an oscilloscope sweep rather than the modulation of incandescent, or other, lamps. The intensity of an oscilloscope sweep can be increased or decreased by applying a negative or positive bias to the cathode of the cathode-ray tube. It can also be accomplished by applying opposite polarities to the control grid of the CRT (a television brightness control operates in this manner). If negative signals are applied to the cathode during a sweep, then the intensity of the sweep increases for each of the negative inputs and the time duration of the increase is equal to the time duration of each of the signals.

A radar PPI scope display is a typical example of intensity modulation. The oscilloscope sweep trace begins at the center of the tube, and sweeps outward. The sweep is initiated (synchronized) by the transmitted pulse; its speed and duration is determined by the range of the radar. Radar echoes are displayed as intensified spots along the range sweep, their position on the sweep being determined by the range of the echo (delay time between transmitted pulse and received signal). PPI scopes are also used to obtain azimuth information.

A second scope, A-scope, is used to determine a more precise range of the radar echo and displays these echoes as an amplitude function. If the detection sensitivity is increased, noise signals may be confused with target echoes and the latter become difficult to identify. Figure 1a is a graphical example of a radar A-scope display (with its polarity reversed) that is saturated with noise. It is apparent that it is virtually impossible to differentiate between noise and targets. It should be remembered that the A-scope display would be repeated at a rate equal to the repetition rate of the radar.

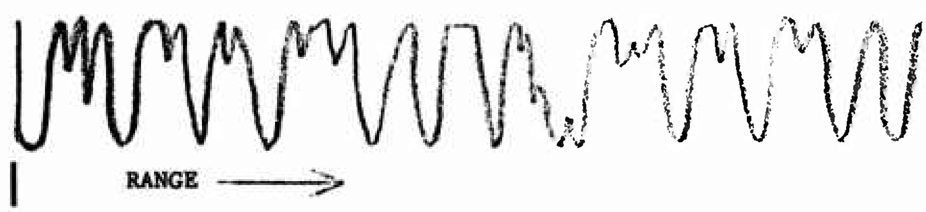

Figure 1a. A typical noise saturated radar A-scope display.

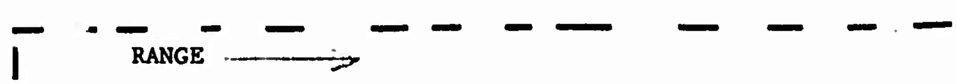

Figure 1b. Intensity modulation of the radar A-scope above.

If the radar A-scope is intensity modulated, as shown in figure 1b, and photographed with a continuously moving film camera, it then becomes possible to detect targets in the presence of noise. Noise signals occur randomly while targets have a range (time) relationship. A graphical example is shown in figure 2.

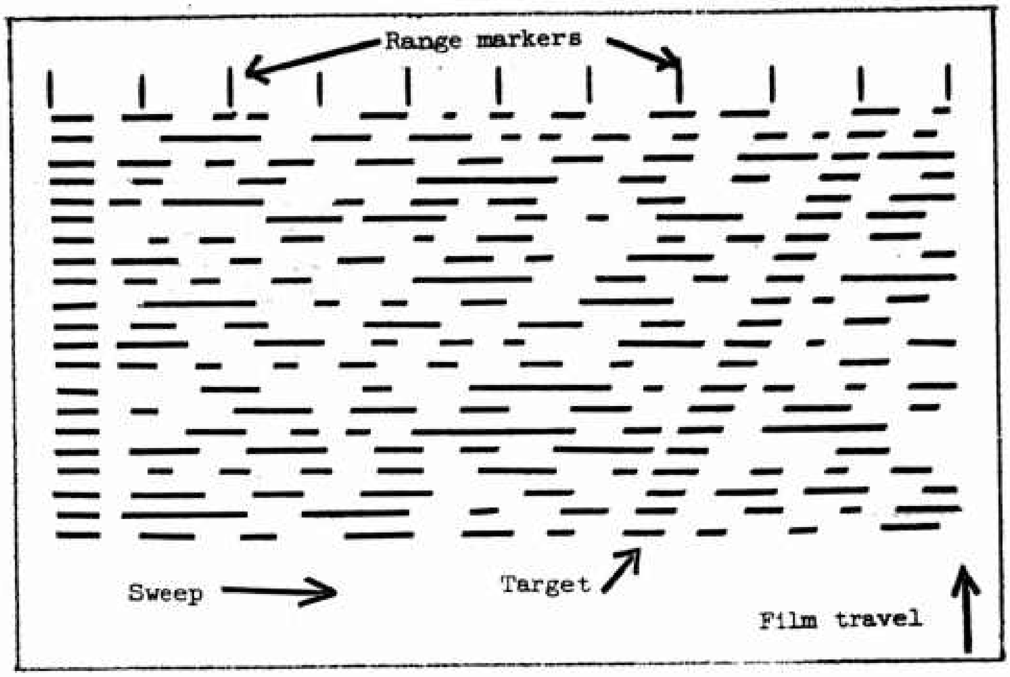

Figure 2. Graphical example of a moving film photograph of an intensity modulated radar A-scope.

The first intensified spot on each of the horizontal sweeps represents the transmitted pulse. This is followed by a series of spots representing noise and target signals. The repetitive sweeps normally occur superimposed upon one another but can be displayed, as shown, if the film moves in a perpendicular direction. The target is readily identified in this example.

If we consider a radar receiver that is remotely located from the transmitter and has an output similar to that shown in figure 1a, correlation would be an impossibility without a synchronizing pulse from the transmitter. However, if the sweep circuits are synchronized to an external time standard, it becomes possible to correlate radar echoes to a real time base. A block diagram of the instrumentation capable of this type of detection is shown in figure 3. An oscilloscope sweep is synchronized to an external time standard. Incoming signals are applied to the cathode of the CRT, which displays these signals as intensified spots along the sweep axis. Signals having a time relationship are considered correlated.

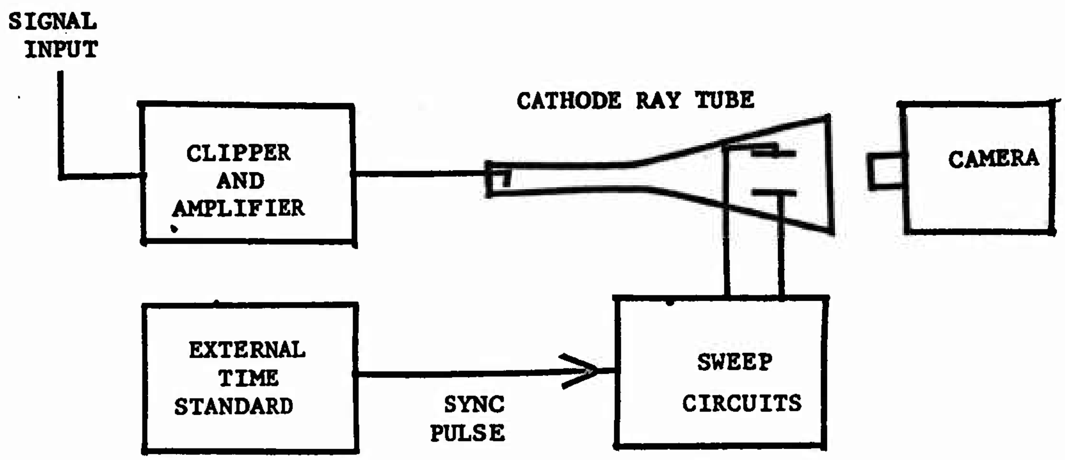

Figure 3. Block diagram of instrumentation used as a correlator.

Examples of moving film photographs are shown in figures 4a and 4b. The sweep axis is vertical in both figures while film movement is horizontal. These film records are part of a back-scatter radar experiment in which ionospheric disturbances were being studied (ref 2). The pulse energy was transmitted obliquely to the ionosphere. Upon reaching the ionosphere, it was reflected to the ground at an angle equal to the angle of incidence. The energy at the ground level was scattered in all directions, and some was reflected back along the path from whence it came. In many instances it was possible to observe multiple reflections.

In figure 4a, the range scope was located near, and synchronized by, the transmitter. The transmitted pulse is the first horizontal trace. Note the sharpness of this trace. The ground reflection is the second horizontal trace. Note the width of this reflection, which indicate a ground reflection from over an area approximately 100 mi long. A second ground return is also visible.

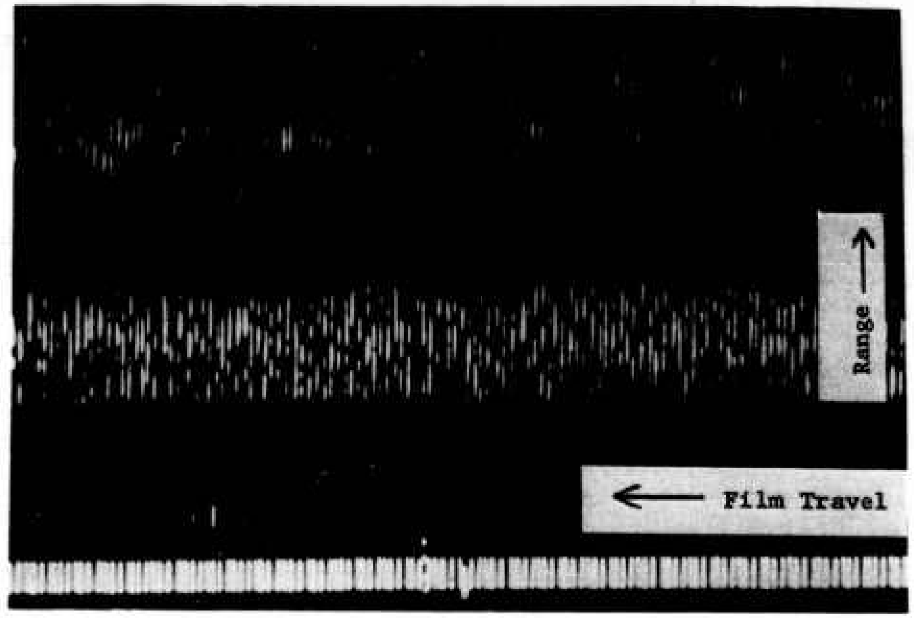

Figure 4a. A back-scatter radar record synchronized by the transmitter.

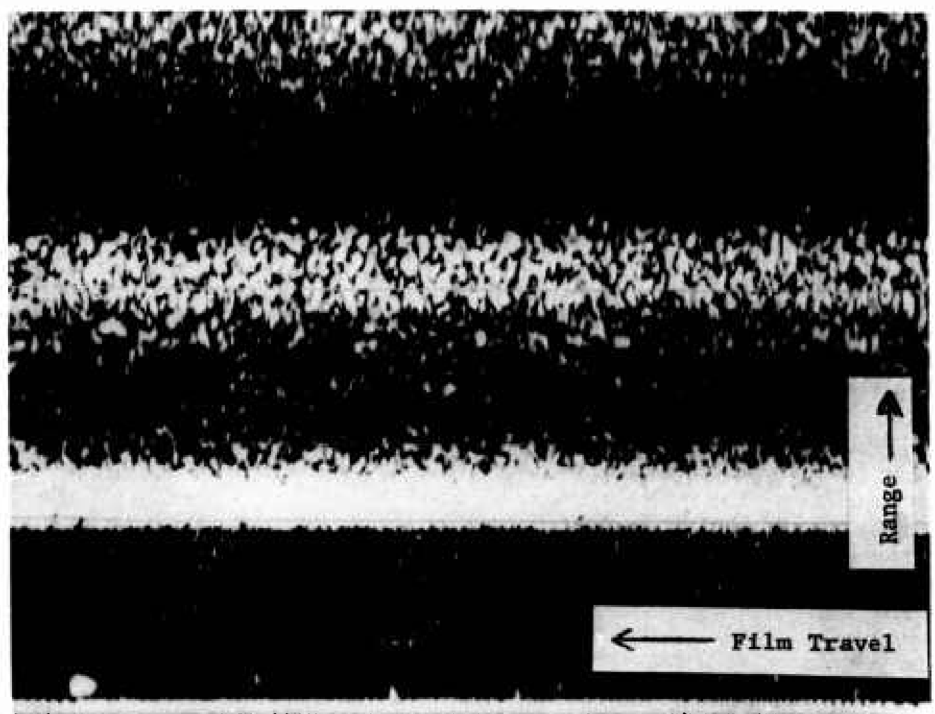

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Figure 4b. A back-scatter radar record synchronized by an independent source.

In Figure 4b, the range scope and associated detection equipment were located approximately 50 mi from the transmitter site. At this location it was impossible to synchronize to the transmitted pulse, therefore, an external time standard, whose frequency output was equal to the pulse repetition rate of the radar, was used to synchronize the range scope. Note the similarity of the ground return signals in these figures even though the equipment sensitivity and film speed differed.

This type of radar synchronization suggests the possibility of establishing a nationwide radar system similar to the National Bureau of Standards' WWV. The system could be composed of existing high-power radars and would enable any research establishment to utilize the facilities without resorting to the expense of purchasing transmitters.

A typical example is in the field of ionospheric studies. Each study group maintains its own transmitters, the cost of which may require a major portion of the funds available. A few well located transmitters, at the proper frequency, could serve as a source of energy for every research group interested in this field. In addition to effecting a substantial saving of funds, the amount of interference in the electromagnetic spectrum would be decreased. Geometry considerations of radar target locators, using passive receivers, are described in reference 3.

3. ANALYSIS OF UNKNOWN SIGNAL PARAMETERS

It has been demonstrated that it is possible to observe a radar transmitter, even though it is located remotely, and to correlate its radar echoes to an external time base. This system can be expanded for use in correlating any type of signal, as a function of time.

Its application to a hypothetical signal input and the determination of the signal parameters can be demonstrated as follows: Assume that a signal input of unknown origin is applied to the oscilloscope. The sweep circuits, including the time standard, are manipulated until the intensified spots on the sweep trace appear to be stationary. The camera is then turned on for a few minutes. A resulting film is shown graphically in figure 5.

The solid horizontal lines represent time (centimeter) markers while the vertical (oblique pattern) dashes represent each negative input cycle. For the purpose of analyzing this figure, we assume the following: Each sweep, shown vertically, traversed the 10-cm width of the oscilloscope at a speed of 1 msec/cm. The external time standard triggered the sweep at a rate of 100 cps and the film speed was 10 in./sec. If these signals are observed visually, they are seen to

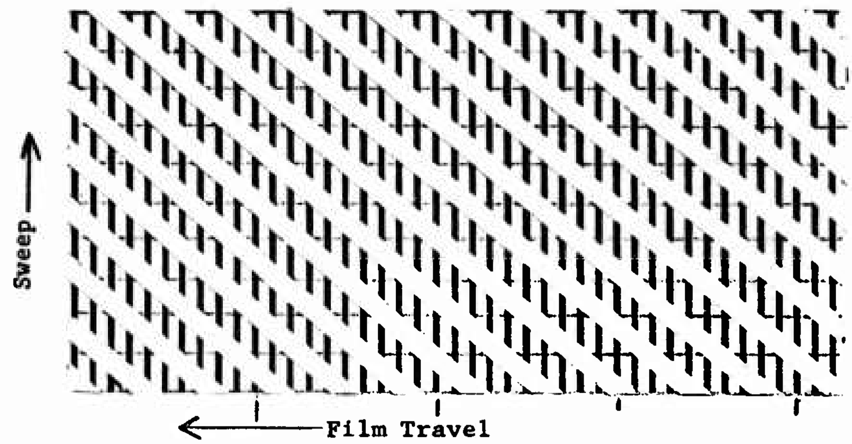

Figure 5. A graphical presentation of an intensity modulated signal.

drift slowly to the left of the oscilloscope (down on the film), indicating that they are not exact multiples of the frequency standard. Our first observation is to note the number of cycles occurring in a sweep. In this case, there are approximately 6 cycles/sweep or a frequency of approximately 600 cps (6 times the frequency standard). If this frequency were exactly 600 cps, it would appear as a horizontal line and since it appears to advance in time, it must be greater. The oblique pattern represents a record of the rate of drift and this rate can be related to a frequency by counting the total number of cycles in a given period of time and dividing by this time as follows:

The frequency is equal to the number of cycles per sweep, times the total number of sweeps per inch of film travel divided by the time rate; time rate equals the time per inch of film travel minus the time advance of a cycle per inch of film travel.

$$f = \frac{\text{no. of cycles/sweep x no. of sweeps/in.}}{\text{time/in.} - \text{time advance/in.}}$$

In this case, there were 6 cycles/sweep, 10 sweeps/in. and a time advance of 4 ms/in. of film travel:

$$f = \frac{6 \times 10}{0.1 - 0.004} = 625 \text{ cps.}$$

It would be simpler to determine the period of one cycle or the number of cycles in one sweep but the film speed is normally in the order of a few inches per minute and the individual sweeps are not discernible. Furthermore, since the negative input cycles are clipped, it would be difficult to determine the exact timing of the individual cycles.

Another method of determining the frequency is to count the number of times an oblique trace crosses a particular centimeter marker for 1 in. of film travel. This figure is added to the total number of cycles occurring in 1 in. of film travel (no. of cycles/sweep x no. of sweeps/in.). This sum is then divided by the time required for 1 in. of film travel and the resultant is the total number of cycles in a known period of time. For example, there are 6 cycles/sweep, 10 sweeps/in., 0.1 in./sec and 8 cross-overs in 3 inches of film travel (2.6/in.) or:

$$f = \frac{2.6 + (6 \times 10)}{0.1} = 626 \text{ cps}.$$

Thus the two methods give frequencies differing by only 1 cps. There are other methods of determining frequencies and/or parameters and the choice would be determined by requirements of the user.

4. OTHER POSSIBLE APPLICATIONS

The technique, described thus far, can be used to study any signal phenomenon from which a time comparison must be made. The accuracy of the system is limited to the accuracy of the external time standard. Crystal oscillators, with a stability of better than 10^{-8}, can be obtained commercially and used for this purpose.

An application of this technique is in phase shift detection where the phase of the incoming signal is compared with the external time standard. A photograph of a phase shift of a 100-cps signal is shown in figure 6. The output of the external time standard was also 100 cps and it initiated the beginning of each sweep. The sweep speed was 100 μsec/cm or 1/10 of the period of the incoming signal. The centimeter markers are therefore calibrated in degrees, 3.6°/cm. The time markers at the lower edge of the photograph indicate 1-min intervals. The signal trace moves upwards by approximately 3/4 cm or 2.7°/min. Since the film moves to the left, the phase of the signal is delayed by 0.045°/sec with respect to the standard.

Figure 7 is another example of this phase measurement. In this example the displayed frequency was 100 cps, the sweep speed was 10 μsec/cm or 0.36°/cm and the synchronizing standard was 10 cps. The incoming signal was sampled every tenth cycle. The camera speed was also increased in order to display the individual sweeps. The phase shift was in the same order as that of figure 6. f7

The two foregoing examples demonstrate the feasibility of this type of measurement. It should be noted that short and long time measurements

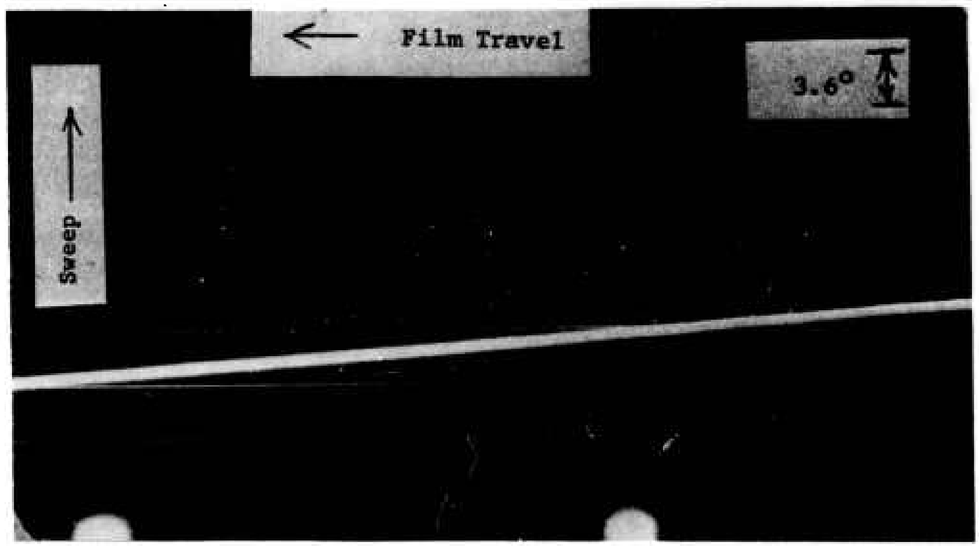

Figure 6. Phase shift display (slow camera speed).

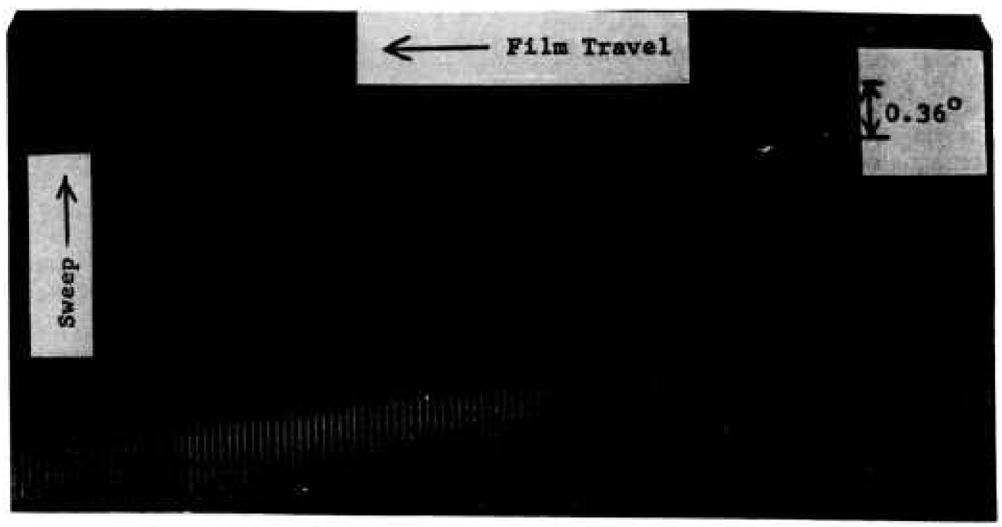

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Figure 7. Phase shift display (fast camera speed).

can be made using this method. Phase accuracies within less than 0.001°/sec can be obtained over long periods of time and lesser accuracies in very short periods of time; i.e., assume that the 20 individual sweeps are the maximum number that are discernible for each inch of film travel at a maximum film speed of 1000 in./min, the sweeps would then occur at 50-μsec intervals. This is the minimum time in which a phase measurement can be made. The maximum time is of course practically unlimited.

The maximum frequencies of which a phase shift can be measured depend upon frequency response of the amplifier, clipping amplitude, sweep speed, and persistence of the phosphor of the oscilloscope. It is possible, however, to use frequency dividers to lower the frequencies. The choice of methods would depend upon the requirements of the user.

Another application of this method is the time comparison of multiple signals. For example, the outputs of a number of receivers could be compared simultaneously, i.e., interferometer systems.

This method can be used to provide a histogram of transmission of a frequency spectrum versus time. In this application the sweep circuits would be synchronized to the drive mechanism of a frequency scan receiver. The sweep would then be calibrated in frequency. A receiver output would be displayed on the sweep as a transmission.

The resulting film would be a recording of the frequency of transmission, as well as the time and duration of these transmissions. A graphical example of an expected recording of this type is shown in figure 8. Each of the horizontal traces represents a frequency transmission and the time of transmission. Note the dashed trace; this would represent a radio beacon transmitting periodically. The broad traces may be indicative of wide-band transmissions or multiple stations.

A similar type of system exists in the military AN/APA-23 recording assembly. This assembly is a specialized adaptor and uses a paper pen recorder. The details of this assembly were not available at the time of this writing. The intensity modulation technique is described because it does not require specialized equipment.

In analyzing tape recorded signals using this technique, it was discovered that the tape recorder speed varied. The speed variations were very small, but significant. This suggested the use of this technique in determining the exact speed variation and the following experiment was conducted:

A 100-cps output, from the frequency standard, was recorded at 15 in./sec. The tape was played back and compared with the standard. If there were no variations in tape speed, the output frequency would be exactly 100 cps and the resultant film would have horizontal traces, the number of which would depend on the sweep speed.

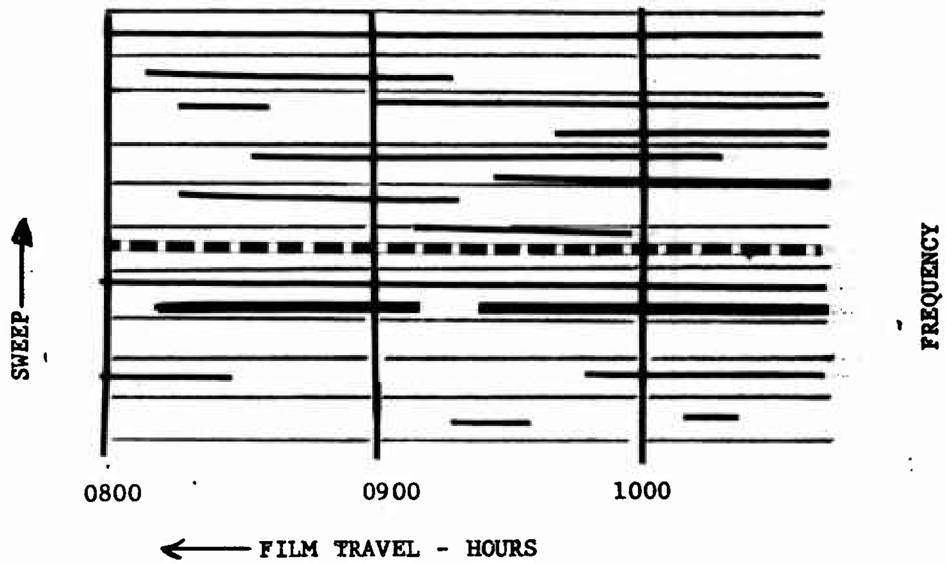

Figure 8. Histogram of frequency versus time.

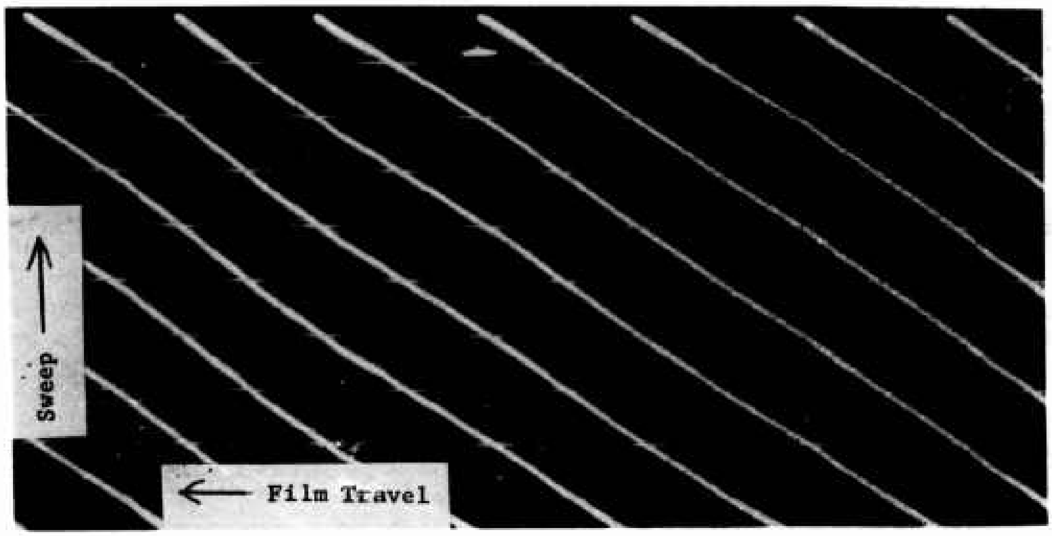

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Figure 9. Tape recorder speed variation versus time.

Figure 9 is a photograph of this experiment. The sweep speed was 5 msec/cm (the period of one cycle is 10 msec or 100 cps) and the camera speed was 2.5 in./min. Each cycle advances in time by 50 msec in 1/3 min or 150 msec/min. Since there are 6000 cycles in a 60-sec period for 100 cps and in this case, 6000 cycles occurred in 60 sec minus 150 msec, the frequency is

$$f = \frac{6000}{60 - 0.15} = 100.25 \text{ cps}$$

This indicates the tape speed is slow by 0.25 percent.

Another method of calculating the tape speed: Each cycle advances in time, indicating a higher frequency. A higher frequency would mean more cycles per inch of tape or a slower tape speed. The time advance of each cycle is 0.15 sec/min, indicating the tape speed of 900 in. in 1 min + 0.15 sec, which is also 0.25 percent.

Another use of the system described here is in telemetry applications. A telemetry signal, directly out of the receiver, can be recorded and the resulting output is in analogue form. This is especially true of pulse time-sharing types of modulation. The system can be classed as a demodulator, and can become a valuable tool in analyzing this type of data. The channels can be analyzed individually in the following manner: Assume there are 6 channels and the repetition rate 60 cps. (Each channel consumes a time period of approximately 2.7 msec and repeats 60 cps). The external time standard output is set at 60 cps and is applied to a delaying circuit. The delayed output is then applied as a synchronizing pulse for the sweep. The sweep speed is adjusted to approximate the time consumed by one channel. The time delay of the synchronizing pulse can now be adjusted to select any channel desired.

It has been demonstrated, in the laboratory, that this technique can effect a substantial saving in time in analyzing signals of this type compared with the more elaborate methods. This statement is not intended to imply that this technique is better than the more elaborate methods, but that it can be used more economically in many instances and further, it can be used to determine design parameters for the more elaborate methods.

5. MODIFICATIONS FOR RAPID OBSERVATION

It is recognized that film development can become cumbersome and time consuming and for many applications, it would be desirable to make immediate observations. For this reason, a Polaroid scope camera was used to replace the moving film camera. To obtain the required scanning action, formerly obtained by film movement, a condenser discharge was applied to the horizontal plates of the CRO (normally these plates are inactive). A condenser discharge is an exponential function and in order to resolve time, the voltage applied to the horizontal plates must be a linear function. However, the feasibility of this scheme can be demonstrated with the condenser discharge.

Two examples of Polaroid photographs of the radar experiment, described earlier, are shown in figure 10. The sweeps in both figures are horizontal while scanning action is vertical. The transmitted pulses are the left vertical traces. Note the interference pattern in both photographs,

An example of the use of this technique as a correlator is shown in figure 11. A high-frequency receiver was tuned to a signal that was barely discernible above the noise. A high-speed keying sound was heard in the background and attempts to synchronize on this signal were unsuccessful. Figure 11a is a photograph of this attempt and it is obvious that the signals appear randomly.

Minutes later, the oscilloscope was synchronized with an external time standard and it became apparent, visually, that a repetitive signal was present. Figure 11b is a photograph of this signal. The basic parameter of this signal, the repetition rate, can easily be determined by noting the time required for the vertical traces to repeat themselves. Figure 11c is the same signal with a higher sweep speed and scanning rate.

This experiment was conducted within a 10 min period and the results are conclusive.

Other experiments were conducted in which a television-type scan was used. The scan was accomplished by manually turning the vertical position control of the oscilloscope and making visual observations. The success of this experiment suggests the possible use of this method for pattern recognition. The operator should be able to adjust the sweep and scan rates to obtain a desired pattern.

6. CONCLUSIONS

It has been demonstrated that intensity modulation techniques can provide a valuable tool in analyzing various signal parameters. In many instances, the use of this technique can offer a substantial saving of time.

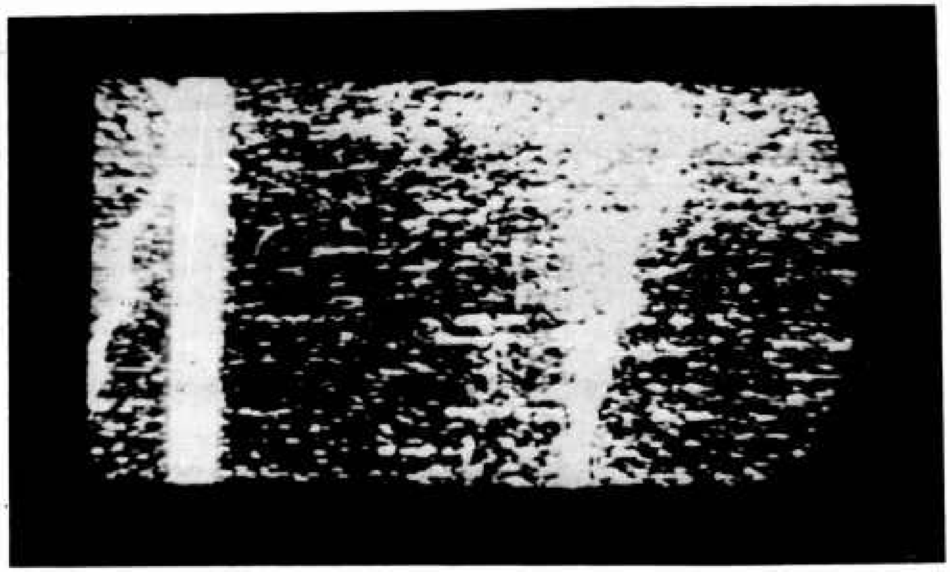
The system described used readily available laboratory equipment although modifications would be advisable for some applications. These modifications would suggest themselves to the user.

Polaroid cameras and television-type scanning can be used for a quick look in detection and/or pattern recognition.

This technique is being investigated to determine the feasibility of its use in doppler detection, coherent detection, and the detection signals in the presence of jamming.

ACKNOWLEDGMENT

The author wishes to express his appreciation to P.W. Griffin and R. Fitzgerald for their helpful suggestions on possible applications of



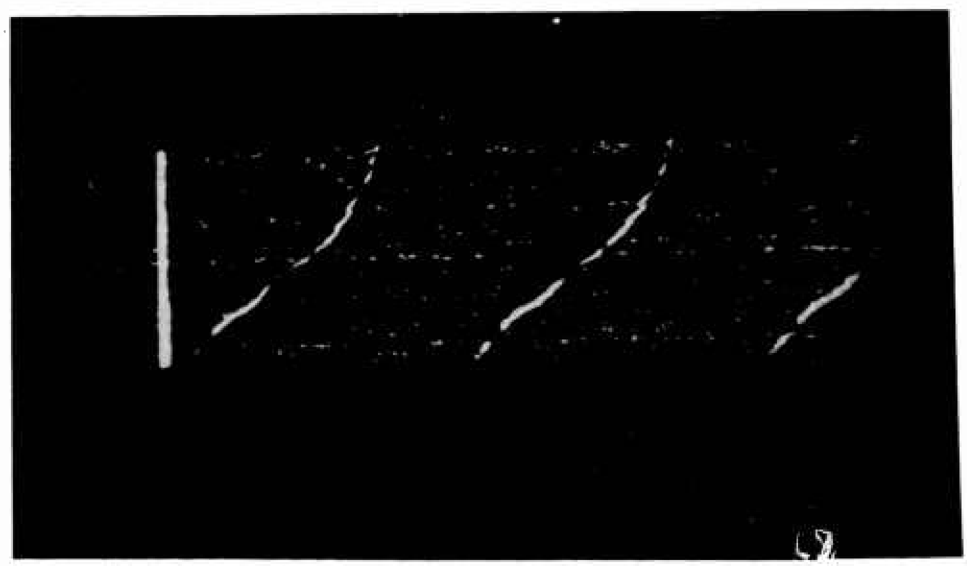


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Figure 10. Polaroid camera pictures of a radar transmission.

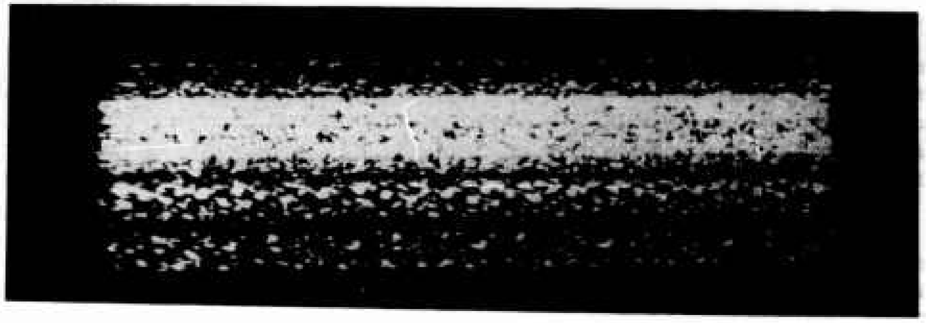

Figure 11a. Polaroid photograph. Sweep synchronized with input signal.

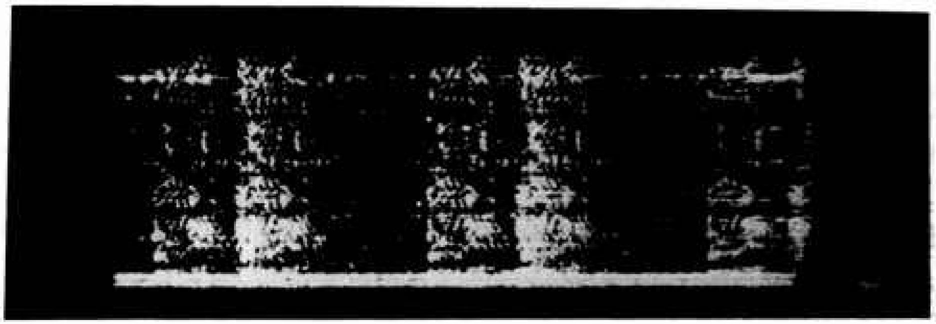

Figure 11b. Polaroid photograph. Sweep synchronized independently.

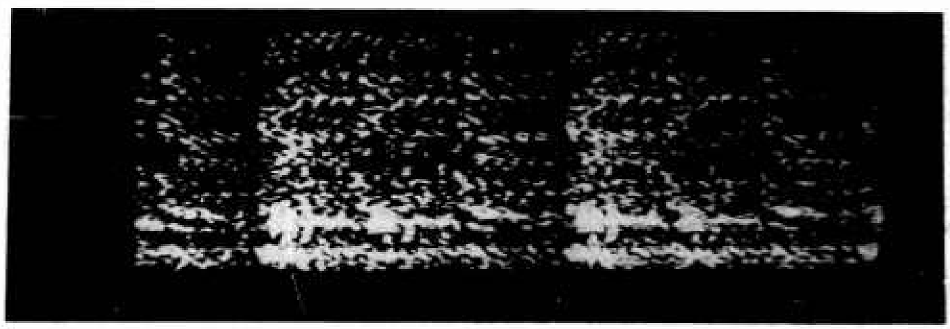

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Figure 11c. Same as above with an increased sweep speed.

this technique and to J. Miller for his suggestions on television-type scanning.

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A simple inexpensive method of analyzing and/or determining signal parameters of unknown purpose or origin, including signals in the presence of noise, is described. The method is an adaption of intensity modulation techniques used in radar systems and employs readily available laboratory equipment. It also employs a moving film camera but techniques for obtaining quasi-instantaneous outputs are described. Other possible uses, such as phase detection, frequency comparison and telemetry evaluation are also described.

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